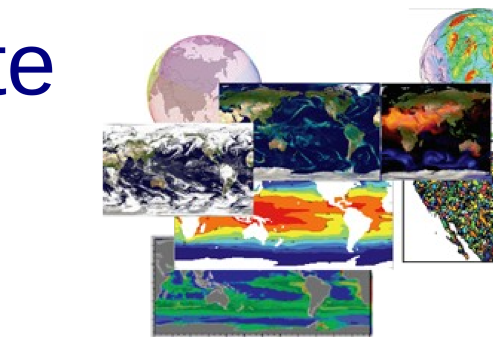
Completing the feedback loop: the impact of chlorophyll data assimilation on the ocean state



Second International Ocean Colour Science Meeting San Francisco, USA, 15-18 June 2015

Anna Borovikov, Christian Keppenne, Robin Kovach
Global Modeling and Assimilation Office, GSFC, NASA, *email: Anna.Borovikov@nasa.gov*

Motivation

Penetration and absorption of solar radiation in the upper layers of the ocean is affected by the optical properties of the water column. The optical properties of the water column in turn are affected by its biochemical composition. The current NASA Ocean Biogeochemical Model (Gregg, 2008) is coupled with an OGCM and forced by prescribed atmospheric data. In anticipation of the integration of the biochemical model into the next generation GMAO fully coupled system, an intermediate solution has been implemented to estimate the penetration depth (*1/Kd_PAR*) of ocean radiation based on chlorophyll concentration, thus allowing for the feedback between the ocean biology component and the general circulation model.

Data and experiments

The GEOS-5 coupled ocean-atmosphere-sea ice model was used for this study. Its components are: the MOM5 ocean model running at 1/2º horizontal resolution with 40 vertical levels, the GEOS-5 atmospheric model running at 1.5ºx1º horizontal resolution with 72 vertical layers and the sea ice model LANL CICE. The chlorophyll is modeled as a tracer with sources/sinks coming from the assimilation of MODIS chlorophyll data. The univariate SAFE (Keppenne et all 2014) was used to processed the chlorophyll data.

Two experiments were conducted. In the first, $CHLO_{clim}$, climatological values of *Kd_PAR* were used. In the second, $CHLO_{assim}$, observed daily chlorophyll concentrations were assimilated and *Kd_PAR* was derived according to Morel et al (2007). No other data was assimilated to isolate the effects of the time-evolving chlorophyll field.

Figure 1 illustrates the amount of data available during a single assimilation cycle, while figure 2 shows the observation count for an entire year. The high latitudes and areas of persistent cloud cover are deprived of observations.

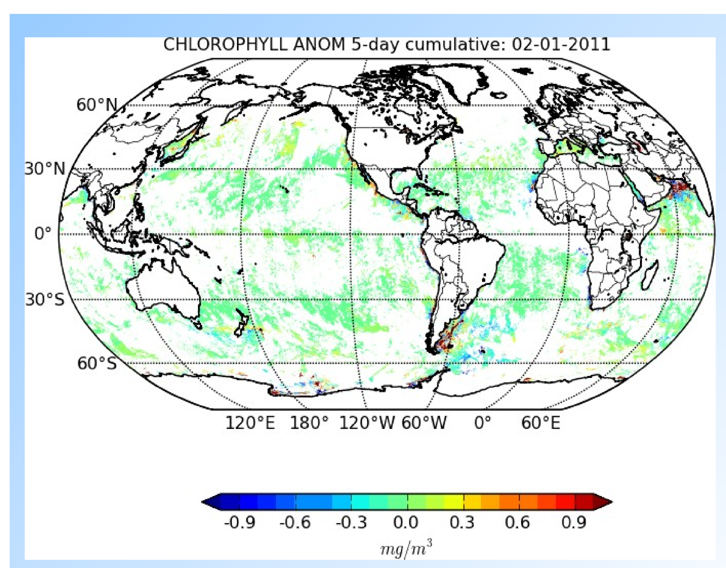


Figure 1: A 5-days composite of chlorophyll concentration anomaly with respect to the 1998-2006 climatology.

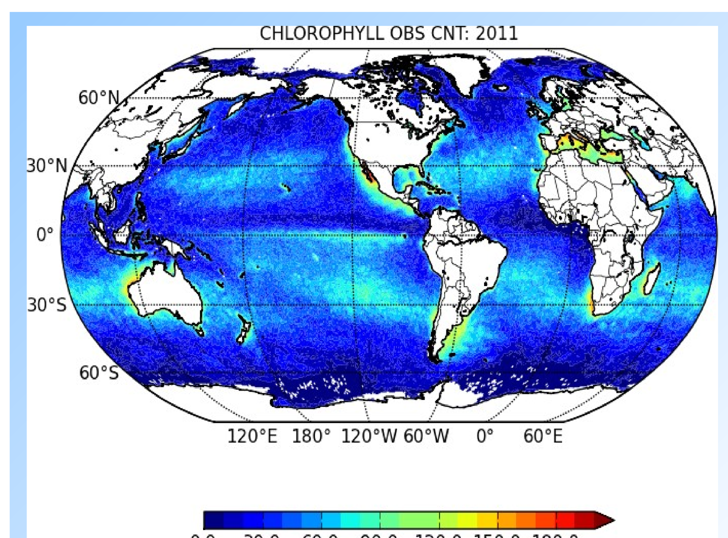


Figure 2: Chlorophyll observations count for 1 year; the observations are binned to the ocean model grid.

Evaluation

The daily MODIS *Kd_PAR* product was used to validate the skill of the penetration depth estimation and the *MERRA-OCEAN* re-analysis was used as a benchmark to study the sensitivity of the upper ocean heat content and vertical temperature distribution to the chlorophyll input. The metrics used to compare the results are the absolute error and the normalized root mean square error, expressed in terms of percentage. In the formula below, X stands for $CHLO_{clim}$, Y for $CHLO_{assim}$ and Z for *MERRA-OCEAN*.

$$Root\ Mean\ Square\ Error = \Delta_{RMSE}\, X:Z = \sqrt{\frac{\sum_{i=1}^{n}(X_i - Z_i)^2}{n}}$$

$$Normalized\ Root\ Mean\ Square\ Error = \Delta_{NRMSE} = \left(\frac{\Delta_{RMSE}\, X:Z - \Delta_{RMSE}\, Y:Z}{\Delta_{RMSE}\, Y:Z}\right) \times 100$$

Penetration depth validation

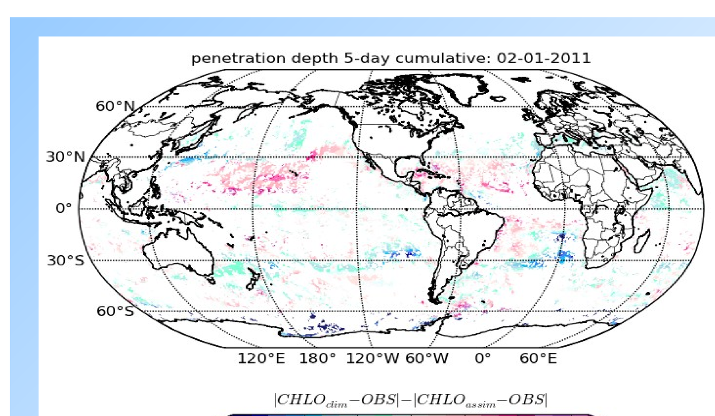


Figure 3: The difference of the absolute errors in the penetration depth with respect to MODIS *Kd_PAR*.

Figure 3 shows a sample 5-day snapshot of the penetration depth from observations compared to simulations. The data coverage is spotty, so to obtain a more robust measure of this difference, a spatial integral of the error was computed and is shown in figure 4. Here the global integral is uniformly smaller for $CHLO_{assim}$ by about 1 *m*, similar to the integral over tropical Pacific Ocean (30ºS-30ºN). The error is generally larger for both experiments and exhibits stronger seasonal variability in the tropical Atlantic Ocean.

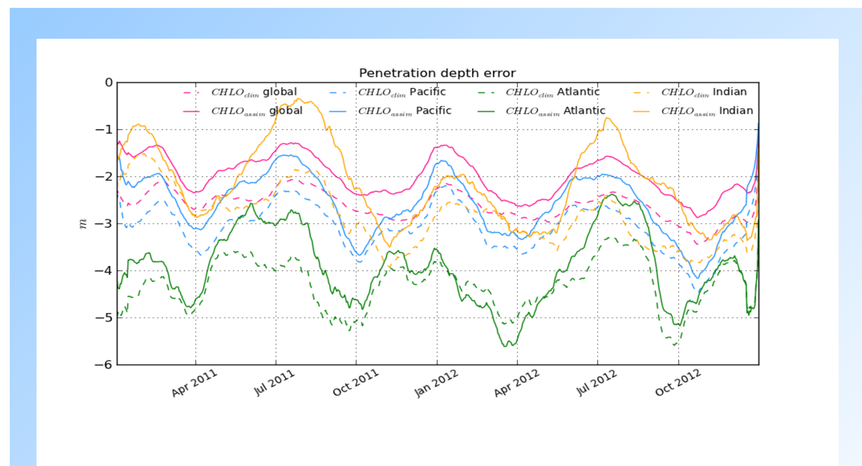


Figure 4: Time series of the integrated penetration depth error, $CHLO_{clim}$ *minus OBS* is shown by dashed lines, $CHLO_{assim}$ *minus OBS* by solid lines.

A similar seasonal enhancement in error amplitude variability in $CHLO_{assim}$ is observed in the Indian Ocean, which reflects the interannual variability in chlorophyll concentration. The overall reduction in penetration depth error may in part be attributed to the interdecadal variability of chlorophyll concentration, since the reference climatology period does not overlap with the experiment dates.

Upper ocean heat content

Figure 5 shows the map of Δ_{NRMSE} of the mean temperature of the upper 50 meters. The pink color indicates the smaller error in $CHLO_{assim}$ over $CHLO_{clim}$. The most uniform improvement is observed in the Pacific basin. In the Atlantic, $CHLO_{assim}$ shows better performance only in the areas off the equator . The error difference in the Indian Ocean is generally smaller, being slightly in favor of $CHLO_{assim}$ in the east and $CHLO_{clim}$ in the west.

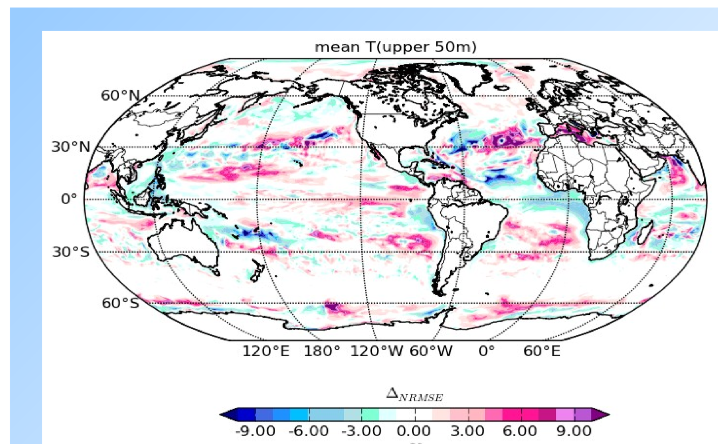


Figure 5. Δ_{NRMSE} for the mean upper 50 *m* temperature.

Temperature vertical profiles

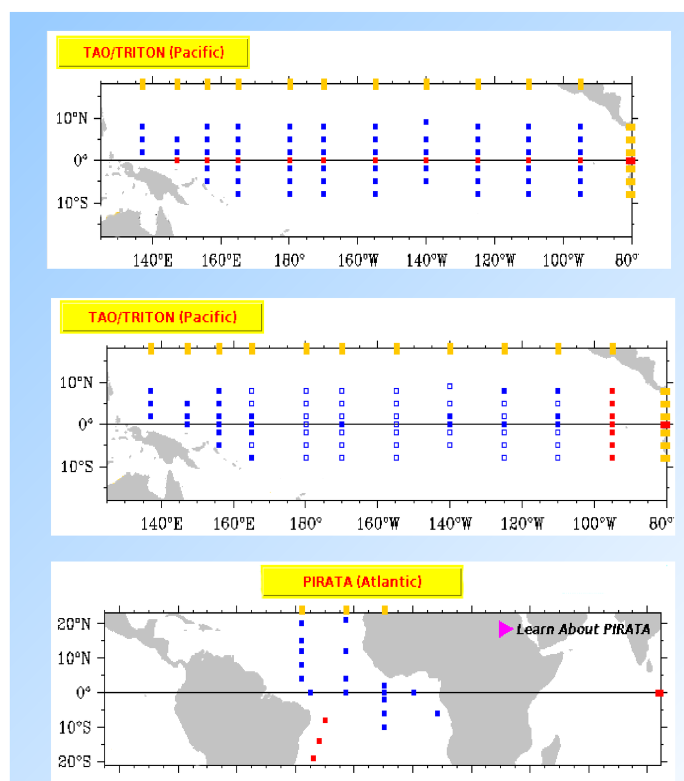


Figure 6. Map of stationary moorings in the Pacific and Atlantic oceans. The red squares mark the locations presented in this study.

The maps in figure 6 highlight the regions most responsive to chlorophyll variability. To look at the effects of the chlorophyll assimilation on the vertical structure of the water column, we selected several locations coinciding with the stationary moorings of the TAO/TRITON and PIRATA arrays. These locations are along the equator in the Pacific Ocean and in the eastern Pacific Ocean cold tongue, as well as in the tropical Atlantic Ocean off the east coast of South America.

Figure 7 displays the difference in absolute error with respect to the *MERRA-OCEAN* reanalysis at the mooring locations along the equator in the Pacific Ocean. Blue and purple solid lines show the absolute error for $CHLO_{assim}$ and $CHLO_{clim}$ *respectively*. Light pink and blue shading show Δ_{NRMSE}.

Pink shading corresponds to improvement in matching the reanalysis temperature, i.e. correcting the model bias, in $CHLO_{assim}$ over $CHLO_{clim}$. The positive impact of assimilating chlorophyll concentration propagates downward to 60 meters in the east and 200 meters in the west. This roughly corresponds to the thermocline depth. The relative gain in skill is between 2% to 5%. Looking along the 95ºW meridian (figure 8), one can see the deeper impact of the chlorophyll assimilation off the equator than at (95ºW, 0º).

As one can see from map of the upper ocean heat content Δ_{NRMSE} (figure 5), there is no significant improvement in the equatorial Atlantic Ocean in the $CHLO_{assim}$ experiment over the $CHLO_{clim}$ run. The positive impact of chlorophyll assimilation on <T(50m)> is found between 30ºS and 10ºS. Thus, we selected moorings located in this region to analyze the vertical temperature profiles (these are marked by red squares in the bottom plot on figure 6). The results are mixed, with the 8ºS location showing a small improvement in skill (1%) in the upper 40 m and then a negative impact below (up to 6%). The 14ºS and 19ºS locations both show the positive impact of the chlorophyll assimilation (5-12%) extending down to 120-150 meters.

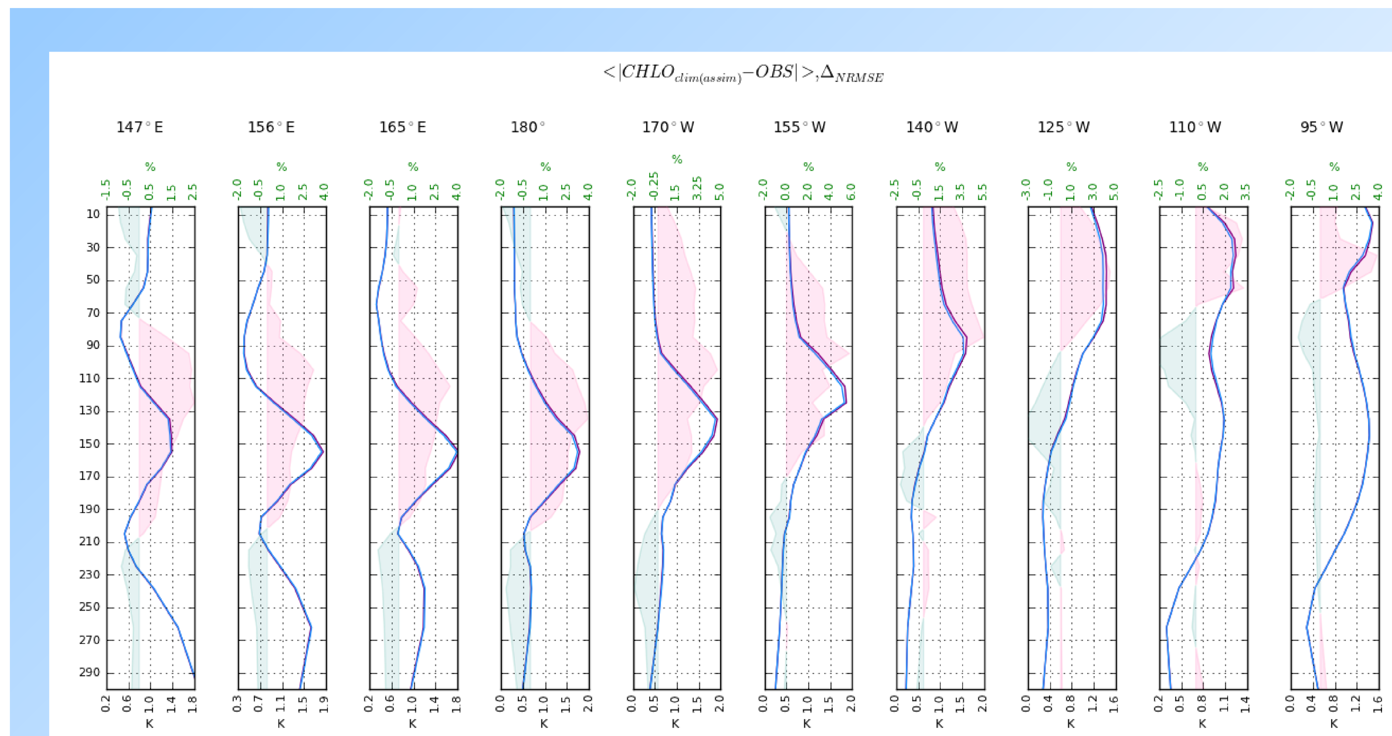


Figure 7.

Figures 7-9: The purple line shows $CHLO_{clim}$, the blue line shows $CHLO_{assim}$ the absolute temperature error computed with respect to the *MERRA-OCEAN* reanalysis which assimilates all available in-situ observations, including TAO/TRITON and PIRATA moorings. The corresponding scale is on the bottom. The scale on the top shows Δ_{NRMSE} in percent with areas of positive values shaded in pink and negative values shaded in light blue.

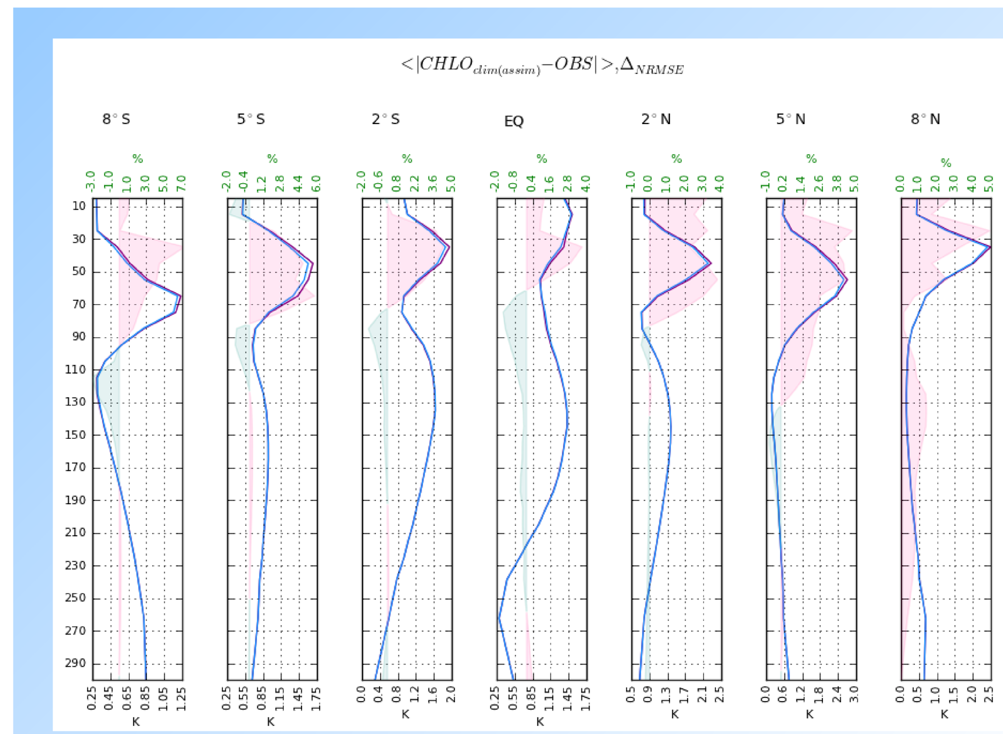


Figure 8.

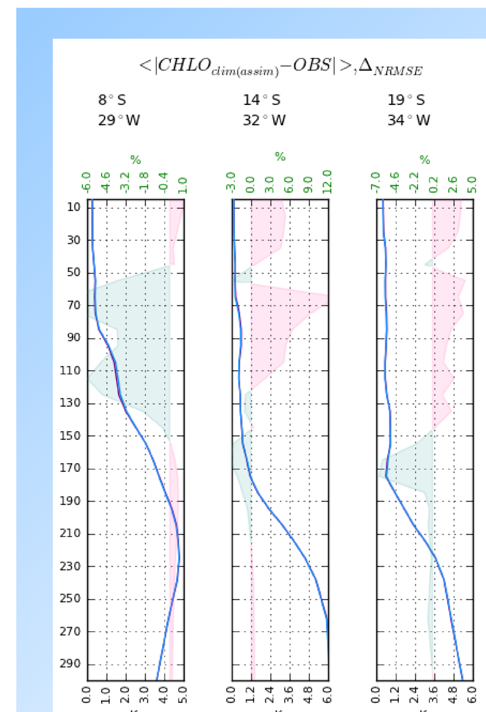


Figure 9.

Conclusion

In the experiment with daily chlorophyll data assimilation, the penetration depth was estimated more accurately, especially in the tropics. As a result, the temperature bias of the model was reduced. A notably robust albeit small (2-5 percent) improvement was found across the equatorial Pacific ocean, which is a critical region for seasonal to interannual prediction.

This study highlighted problems with simple chlorophyll assimilation, such as poor definition of the chlorophyll concentration in poorly observed regions. The implementation of the full biogeochemical model may partly alleviate these problems.

The current limited study will be compared to the assimilation of chlorophyll in a full ocean biogeochemical model.

Acknowledgments

The authors are thankful for the technical help and scientific discussions and criticism to GMAO colleagues Santha Akella, Cecile Rousseaux, Yury Vikhliaev and Guillaume Vernieres.

References

Gregg, W. W., 2008. Assimilation of SeaWiFS Ocean Chlorophyll Data Into a Three-Dimensional Global Ocean Model. Journal of Marine Systems, 69, 205-225.

Keppenne, C. L., M. M. Rienecker, R. M. Kovach, and G. Vernieres, 2014. Background error covariance estimation using information from a single model trajectory with application to ocean data assimilation into the GEOS-5 coupled model. NASA/TM-2014-104606, Vol. 34.

Morel, A., Y. Huot, B. Gentilli, P.J. Werdell, S.B. Hooker, and B.A. Franz (2007). Examining the consistency of products derived from various ocean color sensors in open ocean (case 1) waters in the perspective of a multi-sensor approach, Rem. Sens. Env., 111, 69-85.

Nadiga, S., E. Bayler, A. Mehra, and D. Behringer, 2013. Experiments with Satellite Ocean Color Fields in an NCEP Operational Ocean Forecast System. Poster, GOV Symposium